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Early Standard Model measurements with ATLAS

Tayfun Ince, on behalf of the ATLAS collaboration
University of Victoria, Canada
E-mail: `Tayfun.Ince@cern.ch`

Abstract. The measurement of Standard Model processes will be an important first step towards exploiting the discovery potential of the Large Hadron Collider, the highest energy accelerator ever built that will begin operation in the fall 2009. This paper presents a summary of the early physics analyses for understanding the performance of the detector as well as the Standard Model at the ATLAS experiment at 14 TeV centre of mass energy.

1. Introduction

The Large Hadron Collider (LHC) [1] and the ATLAS detector [2] have been designed primarily for understanding the electroweak symmetry breaking and searching for potential new physics beyond the Standard Model (SM). Reaching such objectives set by the physics program places stringent requirements on understanding the performance of the ATLAS detector and its trigger system, the substructure of proton and the known SM processes in the new experimental conditions.

The analyses presented in the next sections assume 1 fb^{-1} of data or less at 14 TeV centre of mass energy, though it is likely that there will be a period of running at 10 TeV in the first year of the LHC operation. The LHC is capable of delivering 1 fb^{-1} of data in just a few weeks at a moderate luminosity, 2×10^{33} cm^{-2}s^{-1}. The work reported here is based on the full simulation of the detector response to a comprehensive list of physics processes of interest expected to be studied at the LHC. For more details and further studies, see [3].

2. Detector performance

The ATLAS detector will record the signals of the decay products of those particles of interest like the Higgs boson. In general, these are charged leptons, photons, jets of hadrons and missing transverse energy, $E_{\mathrm{T}}^{\mathrm{miss}}$, (e.g. neutrinos). The use of data only techniques to measure the performance of and to calibrate the detector is important during the initial stage of the experiment when Monte Carlo (MC) expectations need to be re-tuned with the understanding of this new energy regime. The well known and understood SM processes with low background rates such as the production and decay of the Z boson, Υ and J/ψ mesons will be used for this purpose.

2.1. Scale and resolution

The design goal for the ATLAS electromagnetic calorimeters was an overall constant term of less than 0.7% in the energy resolution. The local uniformity obtained from test beams and hardware calibration is less than 0.5% in regions of $\Delta\eta \times \Delta\phi = 0.2 \times 0.4$. Inter-calibration of

these regions is possible using $Z \to ee$ events and constraining the invariant mass distribution of electron-positron pairs to the Z boson line shape, well-measured at LEP [4]. The method relies on the precise knowledge of the amount of material in front of the calorimeters. The calibration accuracy obtained from this method is expected to be about 0.4% using only 100 pb^{-1} of data, and hence it is possible to achieve the goal of 0.7% global uniformity. The absolute electromagnetic energy scale can also be obtained from this method and is expected to be known to less than 0.5% for the full E_{T} spectrum up to 500 GeV in the central pseudo-rapidity, $|\eta| < 1.4$, with 200 pb^{-1} of data. With more statistics, the goal is to achieve 0.1% or better on the absolute electromagnetic scale.

The momentum scale and the resolution of muons measured with the ATLAS muon spectrometers can be determined using $Z \to \mu\mu$ events. An accuracy of better than 1% in momentum scale is obtained with 100 pb^{-1} of data. The resolution for transverse momenta in the range 10 GeV/c to 500 GeV/c is better than 4% for the spectrometer with chambers aligned to 30 μm. The resolution degrades in the case of misaligned chambers. For instance, misalignment of the chambers by 1 mm results in a 12% momentum resolution.

The ATLAS calorimeters are non-compensating, and therefore, jets reconstructed from the calorimeter cells that are calibrated to the electromagnetic energy scale need to be re-calibrated to the hadronic energy scale. The accuracy of the jet calibration can be measured using γ+jet or Z+jet events. One of the methods studied in ATLAS is the p_{T} balance method in which the p_{T} of the γ or the Z boson ($Z \to ll$ decays in particular) is compared to that of the jet to determine the absolute hadronic energy scale. For high p_{T} in the range 100 GeV/c to 500 GeV/c, γ+jet events are used, and the energy scale should be known to a statistical precision of better than 1% with 100 pb^{-1} of data. At low p_{T}, Z+jet events maybe used due to lower QCD multi-jets background rates resulting in a statistical uncertainty on the energy scale of less than 1% that can be achieved with 300 pb^{-1} of data.

The $E_{\mathrm{T}}^{\mathrm{miss}}$ scale can be measured to better than 8% with 100 pb^{-1} of data using $Z \to \tau\tau$ events with one τ decaying leptonically. The $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution is determined using $Z \to ee$ or $\mu\mu$ events, which should in principle have no missing energy. The resolution in the direction longitudinal to the Z boson momentum is about 3.5 GeV when the scalar sum of the energy, $\sum E_{\mathrm{T}}^{\mathrm{cluster}}$, in the hadronic calorimeters is 20 GeV and is better than 6 GeV for $\sum E_{\mathrm{T}}^{\mathrm{cluster}} = 100$ GeV.

2.2. Efficiency determination

The trigger, reconstruction and identification efficiencies of leptons can be determined from data only using a technique called tag & probe. The Drell-Yan resonances Z, Υ and J/ψ will be used to calculate the desired efficiency depending on the lepton p_{T} range of interest.

In the tag & probe method, one first selects a fairly clean (low background) sample of events with two potential lepton candidates whose invariant mass is required to match those of one of the resonances considered. One of these lepton candidates is required to have passed all the selection criteria including trigger and is called the tag. The other one is tested for a particular selection to determine the efficiency and is called the probe. The method is found to give consistent results with MC predictions. The systematic uncertainty of this method is better than 2% when the Z resonance is used. The charge misidentification rate obtained using the tag & probe method is less than 0.2% in the central pseudo-rapidity region.

3. Probing the substructure of proton

Determining the cross sections of observed physical processes is important when studying a new energy regime and searching for new physics. In order to calculate a cross section at the LHC, one needs to know the probability of finding a particular pair of partons interacting at a momentum transfer Q and carrying certain fractions, x of the proton momentum. Such information is provided in the form of Parton Distribution Functions (PDFs), and currently

these distributions have to be determined from experimental data. Since the LHC kinematic range in x and Q is much bigger than any previous experiment, PDF uncertainty is one of the most dominant systematics, and it can limit discovery potential for new physics.

In ATLAS, various measurements are envisioned to further constrain PDFs. The rapidity distribution, $\mathrm{d}\sigma/\mathrm{d}y$, of the Z boson and invariant mass spectrum, $\mathrm{d}\sigma/\mathrm{d}m_{ee}$, of low mass (20 GeV/$c^2$ - 60 GeV/c^2) Drell-Yan lepton pairs can be used to constrain sea quark PDFs and low-x theory in general. The W boson and γ+jet events will be used to improve gluon PDFs. A 40% reduction in gluon PDF uncertainty should be obtained using 50 pb^{-1} of $W \to e\nu$ data [5].

4. Electroweak measurements

Measurements of the inclusive production cross sections of the W and Z bosons are crucial in understanding the SM at energies never before studied as well as testing of precise theoretical expectations. At 14 TeV, the production cross sections of the W and Z bosons decaying into leptons are about 20 nb and 2 nb, respectively. The measurement of the masses of the W boson and the t quark at ATLAS will improve upon the already very precise values of these parameters and will further constrain the predicted mass of the SM Higgs boson. Further improvement on the precision of the masses of the W and t will only be possible with much more than 1 fb^{-1} of data.

4.1. W and Z cross sections

The typical selection of $Z \to ee$ or $\mu\mu$ events includes using a single lepton trigger, finding a pair of oppositely charged leptons of invariant mass in the range $m_Z \pm 20$ GeV/c^2, requiring each lepton to have $E_{\mathrm{T}} > 15$ GeV, $|\eta| < 2.5$ and to be isolated. The most dominant background comes from QCD multi-jet events. The expected statistical uncertainty on the cross section is already less than 1% with 50 pb^{-1} of data, while the systematic uncertainty is about 4% excluding the uncertainty on the luminosity which is expected be better than 30% at the early stages of data taking.

The $W \to e\nu$ or $\mu\nu$ events are selected similarly with a single lepton trigger, finding an isolated lepton with $E_{\mathrm{T}} > 25$ GeV and $|\eta| < 2.5$, an $E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV and requiring the transverse momentum m_T^W of the W be greater than 40 GeV/c^2. QCD multi-jets background is also the most dominant in this case. The statistical uncertainty is about 0.2% with 50 pb^{-1} of data. A 5% systematic uncertainty is expected excluding the luminosity uncertainty.

4.2. W boson and t quark masses

The measurement of the W mass cannot be made directly due to the neutrino from the W decay escaping undetected. Instead, the p_{T}^l of the lepton or the m_{T}^W of the W boson, both of which are sensitive to the mass, can be used. The p_{T}^l distribution has a Jacobian peak at $m_W/2$, whilst the m_{T}^W peaks at m_W.

The selection of $W \to l\nu$ events include using a single lepton trigger, requiring an isolated lepton of $p_{\mathrm{T}} > 20$ GeV/c and $|\eta| < 2.5$, an $E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV and ensuring that the hadronic recoil p_{T} is less than 50 GeV/c. For electrons, the barrel-endcap transition region ($1.3 < |\eta| < 1.6$) of the calorimeter is also excluded from selection. In order to determine the mass of the W, template distributions of p_{T}^l and m_{T}^W are generated with various assumed values of m_W, smeared for detector response and compared to the measured distribution to find the best matching template and therefore the mass of the W. The $Z \to ee$ or $\mu\mu$ events are used to measure the detector response. The uncertainty on the mass of W using p_{T}^l method with 15 pb^{-1} of data is expected to be $\Delta m_W = 120(\mathrm{stat})\pm117(\mathrm{sys})$ MeV/c^2 in the electron channel. The most dominant uncertainty comes from the lepton energy scale. With the m_{T}^W method, the uncertainty on m_W is $\Delta m_W = 57(\mathrm{stat})\pm231(\mathrm{sys})$ MeV/c^2 estimated in the muon channel. The $E_{\mathrm{T}}^{\mathrm{miss}}$ scale is the most dominant source of uncertainty in this method. The most dominant theoretical

uncertainty for both methods is the uncertainty on the PDFs. One important property of m_{T}^{W} is its independence of the p_T of the W. Thus, this distribution is much less sensitive to the modelling of the W boson recoil.

The t quark mass, m_t, will be measured at ATLAS using $t\bar{t}$ events. The production cross section of $t\bar{t}$ pairs is about 0.83 nb at 14 TeV. The most promising channel for a precise measurement is expected to be the semi-leptonic decay in which one of the W bosons decays leptonically while the other decays hadronically resulting in a lepton, an $E_{\mathrm{T}}^{\mathrm{miss}}$ and four-jets signature, with two of the jets coming from the b quarks. Events are selected with a single lepton trigger and must have a lepton of $p_{\mathrm{T}} > 20$ GeV/c, an $E_{\mathrm{T}}^{\mathrm{miss}} > 20$ GeV and at least four jets, three of which with $p_{\mathrm{T}} > 40$ GeV/c and one with $p_{\mathrm{T}} > 20$ GeV/c.

There are many studies performed in ATLAS to determine m_t. Two of those methods are the χ^2 and the geometric method. The goal of both methods is to find those three jets (one must be a b-jet) which come from the hadronically decaying t quark and are to be used for the mass determination. The χ^2 method makes use of the b-tagging capabilities of the detector to reduce the combinatorial background and applies a χ^2 minimization to find the two light jets which come from the W decay. The χ^2 minimization constrains the mass of the light jet pair to m_W by re-scaling energies of the jets. The light and b-jet energy scales are the most dominant systematic uncertainties for the χ^2 method. The effect of these scales on the t quark mass uncertainty is 0.2 GeV/c^2/% and 0.7 GeV/c^2/% respectively. For example, a 1% b-jet energy scale uncertainty gives an expectation of a 0.7 GeV/c^2 uncertainty on the mass of the t quark. Assuming both the light and b-jet energy scale uncertainties are known to 1%, the total systematic uncertainty on m_t with this method is about 1 GeV/c^2. The statistical uncertainty is less than 0.4 GeV/c^2 with 1 fb^{-1} of data. The geometric method, on the other hand, does not use b-tagging and is complementary to the χ^2 method especially during the early stages of the experiment until the detector calibration matures. This method simply chooses the two geometrically closest jets with invariant mass around the m_W. Lack of b-tagging in the geometric method results in a higher rate of combinatorial background and an uncertainty of about 1 GeV/c^2 on m_t. The overall systematic uncertainty on m_t with this method is 2 GeV/c^2 assuming 1% uncertainty on the jet (light or b) energy scale.

5. Conclusions

Studying SM processes and re-measuring its parameters are not only important for understanding of the ATLAS detector, but are also essential in order to be able to discover new physics. The statistical uncertainties on SM measurements will be negligible at LHC. Therefore it is possible to improve the uncertainty even on the already precisely measured SM parameters as understanding of the response of the ATLAS detector advances.

References

[1] L. Evans and P. Bryant (editors), *LHC Machine*, JINST 3 (2008) S08001

[2] The ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, JINST 3 (2008) S08003

[3] The ATLAS Collaboration, G. Aad et al., *Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics*, CERN-OPEN-2008-020, Geneva, 2008

[4] The ALEPH, DELPHI, L3, OPAL, SLD Collaborations, the LEP Electroweak Working Group, the SLD Electroweak and Heavy Flavour Groups, *Precision Electroweak Measurements on the Z resonance*, arXiv:hep-ex/0509008 v3, 2006

[5] A. Tricoli, A. M. Cooper-Sarkar, C. Gwenlan, *Uncertainties on W and Z production at the LHC*, HERA - LHC Workshop Proceedings, arXiv:hep-ex/0509002 v1, 2005.